THIRD EDITION

ENGINEERING
DESIGN PROCESS

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YOUSEF HAIK | SANGARAPPILLAI SIVALOGANATHAN | TAMER M. SHAHIN

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Engineering Design Process

Third Edition

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Engineering Design Process, Third Edition
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Library of Congress Control Number: 2016952377

ISBN: 978-1-305-25328-5

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Printed in the United States of America
Print Number: 01 Print Year: 2016

TO OUR PARENTS, WIVES,
AND CHILDREN.

TO FUTURE DESIGNERS.

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PREFACE

Design is the practice of turning "dreams of wonderful products" into reality. It converts an abstract idea to a tangible physical product. The complexity of any design stems from the abstraction of the idea, the unknown aspects of the "wonderful product dreamt", and the identification of the best combination of creativity, science, and technology used to realize it. Thus, the challenges facing the designer are (1) defining the problem well, and (2) identifying the optimal solution.

In traditional practice, the designer handles these challenges in private and this ability is treated as natural talent. *Engineering Design Process* presents the model of systematic design, which challenges the assumptions of traditional design practice and makes the design process transparent so that any motivated person can engage in design and produce dream products.

We have taken special consideration of the needs of undergraduate students taking a design course. We describe an orderly process of collecting, recording, and analyzing all facts to enable students to realize physical products that meet societal needs. The book makes it easy for students at various levels to follow the design process as different methods at each stage of the design process are introduced. The technical analysis component of the design was kept at an introductory level so that students with technical capabilities at the level of college physics and calculus can easily understand the analysis component. The book can be used by first- and second-year students starting out in design while still being a useful reference for students working on capstone projects and entering professional practice.

NEW TO THIS EDITION

This third edition introduces the systematic design process in five stages:

1. Requirements
2. Product concept
3. Solution concept
4. Embodiment design
5. Detailed design

This design model tackles the two primary challenges to designers: (1) ill-defined design problems, and (2) unknown solution spaces.

The third edition presents methods in each of the design stages designed to lead the reader towards the optimal design solution. New methods are added in all of the five stages. New relatable, easy to comprehend examples have been presented.

The five stages are presented in a coherent fashion to help students navigate the design model systematically with supporting exercises and labs. A new lab in Chapter 1 introduces beginner designers to the design process and helps show how to apply the methodology in engineering and other design problems.

TRUSTED FEATURES

This book incorporates a consistent approach to teaching the engineering design process, making it easily comprehensible to all engineering students. Students learn how to regularly and carefully follow each important step, including identification of a need and setting goals, market analysis, specifications and constraints, function analysis, generating concepts, evaluating alternatives, embodiment, analysis, experiment, and marketing.

Particular care is taken to emphasize the issues students need to consider before proceeding with the design process. These key prerequisite considerations include scheduling, human factors, safety considerations, and presentation style.

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Examples, activities, and labs ensure students have the knowledge and skills necessary to succeed as practicing engineers. Practical, illustrative examples throughout the text clarify and visually reinforce the key steps in engineering design and show how the material is applied. Design labs are integrated into each chapter. In addition to giving students important practice in teamwork as part of the design process, these projects help students practice material selection, ergonomics, finite element method analysis, geometric tolerance, and scheduling.

ORGANIZATION

The book consists of 15 chapters divided into seven parts. We recommend reading each part completely and thoroughly before embarking on that stage. This will help the reader to decide the tools, methods, and approaches to be used at each stage of the design project.

- Chapter 1 presents an overview of the design process with an introductory discussion on the five stages design model and some of the design methods for each of the stages. The Chapter highlights the design challenges, broadly reviews the various aspects associated with design, illustrates conventional design, summarily describes systematic design process, explains how the function providers of a complex machine can be conceptualised as integration of simple and individual function providers. An illustrative example "a tale of developing a sandwich" is introduced in Lab 1 to orient beginning design students and to demonstrate the versatility of this text's design model. This is a 'must read chapter' for anyone using this book.
- **Part 1: General:** Covers the general skill set and norms used by a successful professional engineer. Students should master them before embarking on the use of systematic design process. Chapter 2 covers the basic competencies students need to succeed in the design process, including working in teams, scheduling, research skills, technical writing, and presentation skills. Chapter 3 discusses ethics and professionalism, including the Code of Ethics developed by the National Society of Professional Engineers.
- **Part 2: Requirements:** The genesis of a product starts with the design brief stating "what the product is" and the list of customer requirement stating "what the product would or should do" as expected by the customer. This part covers these in detail. Chapter 4 describes how market information is gathered by senior management to establish the design brief. The design brief is the first document that defines what the product is and the constituent elements are also described in Chapter 4. Chapter 5 describes how to determine customer requirements, then standardize and prioritize them. The set of requirements thus established describe what the product would or should do.
- **Part 3: Product Concept:** This part describes the design model consisting of functional description and specifications. Chapter 6 covers the process of establishing function structures, starting with describing the product with its physical and functional elements, creating a function tree for a product, and developing function structure in terms of flow for a product. Chapter 7 explains how to identify and define specifications based on customer requirements.
- **Part 4: Solution Concept:** This part describes the conceptual design methods, evaluation of alternatives, and assembling and assessing prototypes. Chapter 8 covers concept design, showing how to create morphological charts, use systematic methods to generate function-based designs, conceptual designs, and analyze and evaluate conceptual design approaches. Chapter 9 discusses the various methods for evaluating concepts developed in the previous stages, including using decisions matrices and Pugh's concept selection.
- **Part 5: Embodiment Design:** The design starts to take shape in this stage. Chapter 10 provides an overview of prototyping concepts and practices, including design for "X." Chapter 11 covers the steps needed for the embodiment design stage to bring together the stages of concept design and detail design.

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- **Part 6: Detailed Design:** The last step in the synthesis is to make the design complete with every detail and to prove the design with the necessary analyses. Chapters 12 and 13 introduce methods to generate detailed design and design analysis.

- **Part 7: Closure:** This section brings together all of the concepts introduced in the book. Chapter 14 presents a detailed case study of designing a single stage scissor platform and Chapter 15 presents a list of project descriptions that can serve as an entry point to instructors' assignments.

The design labs are integrated within the chapters. The purpose of these labs is to create design activities that help students, especially first and second year students, to adjust to working in teams. The first few labs are geared toward team building. Instructors may want to include other activities in their design classes.

SUPPLEMENTS

An instructor's solutions manual and Lecture Note PowerPoint Slides are available via a secure, password-protected Instructor Resource Center at https://login.cengage.com/.

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Engineering Design Process is also available through **MindTap**, Cengage Learning's digital course platform. The carefully crafted pedagogy and activities in this textbook are made even more effective by an interactive, customizable eBook, automatically graded assessments, and a robust suite of study tools.

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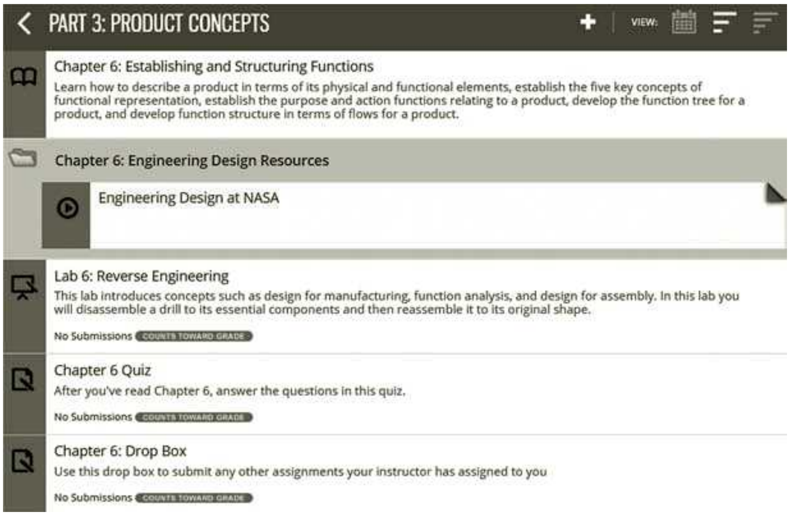

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ACKNOWLEDGMENTS

The authors wish to thank Patrick Tebbe, Minnesota State University, Mankato, and Patricia Buford, Arkansas Tech University for their helpful suggestions.

The authors also wish to acknowledge and thank our Global Engineering team at Cengage Learning for their dedication to this new book: Timothy Anderson, Product Director; Ashley Kaupert, Associate Media Content Developer; D. Jean Buttrom, Content Project Manager; Kristin Stine, Marketing Manager; Elizabeth Brown and Brittany Burden, Learning Solutions Specialists; Teresa Versaggi, Product Assistant; and Rose Kernan of RPK Editorial Services, Inc. They have skilfully guided every aspect of this text's development and production to successful completion.

Students have been and are the inspiration behind this book. A lot of their work has initiated the thought process in several examples. Their contributions are very much appreciated. The authors are grateful to all colleagues and students who helped in producing this book. Students and instructors are encouraged to submit their comments and suggestions to the authors by emailing globalengineering@cengage.com.

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CHAPTER 1

INTRODUCTION

"The life and soul of science is its practical application."

~Lord Kelvin

Systematic design process is a sequence of stages with a design model and a combination of design methods, which are tools and techniques usable at different stages of the design process. We start by providing an overview of the design process by explaining the nature and definition of design, the design solution space, and the two challenges of design. These are (1) defining the problem right and (2) identifying and developing the unknown optimal solution from the unknown solution space. We will also explore the traditional design process, which can lead to a satisfactory solution. The systematic design process is introduced at this point together with a brief explanation of the systematic design process adopted in this book. Following that is a discussion of the systematic design process as advocated by two other authors. The chapter concludes with an explanation of the book's structure.

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1.1 OBJECTIVES

By the end of this chapter, you should be able to

1. Explain and define design.
2. Appreciate the importance and challenges of design.
3. Understand the need for a formalized systematic design process.
4. Name and describe the stages for the systematic design process.
5. Distinguish between different systematic design models.

1.2 NATURE AND DEFINITION OF DESIGN

A design problem is the characterization of a societal *need*. It describes a problem in society for which solutions are needed. A design problem characterizing a societal need typically has several possible solutions, and all possible solutions constitute the design solution space. Some of these solutions may be (1) high-tech while others are not, (2) expensive while others are not, (3) efficient while others are not, (4) manual while others are not, (5) developed by people who have limited theoretical knowledge but do have a wealth of experience (e.g., craftsmen) or not, and (6) acceptable solutions according to some criteria or not. Acceptable solutions meet several requirements, whereas the optimal and near-optimal solutions meet most of the requirements. They are subsets of the acceptable set of solutions. In a Venn diagram the situation can be mapped as shown in Figure 1.1.

Two characteristics of a design problem are that (1) the problem is ill defined and (2) the solution space is unknown. *The challenge is to define the problem well and then identify the optimal or near-optimal solution from the unknown solution space in an efficient way.*

For example, a need statement may read "researchers often refer to more than one book while reading and taking notes. They **need** *a mechanism or appliance to keep these books open by the side for prolonged periods when they refer and cross-refer.*" This is a design problem that needs a solution. The loose nature of this need permits several design solutions that could very well satisfy the need and could be fascinating and exciting as well.

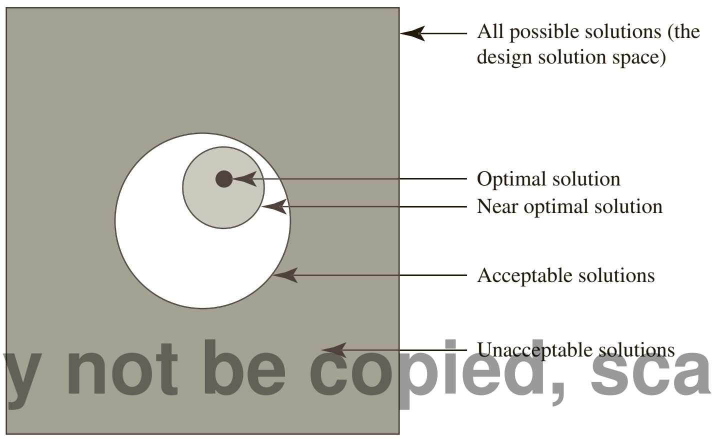

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Figure 1.1: Design Solution Space

Identification of design problems is one of the crucial parts of product design and development. All design problems have certain common characteristics:

1. There are several possible solutions to the design problem.
2. The problem solver must formulate the potential solution.
3. Often proposed solutions provide better insight into the problem.
4. Solutions are not right or wrong; instead they range from better to not-so-good.
5. The designer needs to choose from the alternatives according to some implicit or explicit criteria. In this book an *objective-based method* is prescribed as the basis for the criteria and their weighting.

Design refers either to the product that has been designed or the process that has been followed to produce the design. This book focuses on the design process.

In the 1960s a committee from the Science and Engineering Research Council of the UK [1] described engineering design as "the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency." A task force for the U.S. National Science Foundation defined the new discipline called *Design Theory and Methodology* [2]. In this discipline, design theory refers to "systematic statements of principles and relationships, which explains the design process and provides a useful procedural way for design. In the same way the methodology refers to the collection of procedures, tools and techniques, which the designer may use in applying the design theory to the process of design."

The task force stated that the new discipline has two constituent parts called (1) conceptual design and innovation and (2) quantitative and systematic methods. Another formal definition of engineering design can be found in the curriculum guidelines of the Accreditation Board for Engineering and Technology (ABET). The ABET definition [3] states that "engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to optimally convert resources to meet a stated objective."

In another approach, adapted from Gero [4], an analytical model for a design can be given as a function in the following way:

$$D = f(F, B, S, K, C)$$

Where

D = Design of the product
F = Functions intended to be performed by the product
B = Behavior of the structural elements that provide the intended functions
S = Structural attributes
K = Knowledge used in the design
C = Context of the product

The fundamental elements of the design process include the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. It can be viewed from several different perspectives as explained in sections 1.3.1 to 1.3.3. From these definitions it is evident that design is both a scientific and a creative process. Albert Einstein's assertion "imagination is more important than knowledge, for knowledge is finite whereas imagination is infinite" reaches its full embodiment in design.

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In this book, we will describe an orderly design process of collecting, recording, and analyzing all facts to enable beginner designers to define the problem sufficiently well as well as steps for identifying a near-optimal or optimal solution and its complete definition.

1.3 THE CHALLENGES OF DESIGN

The challenges of design are two-fold: (1) defining the problem and (2) identifying the solution. When any one of these is not done well, the design can fail to produce the expected results. The systematic design process was introduced to help guide designers to achieve their goals without hindering creativity. Classifying the design task as a set of categories helps to eliminate a significant part of the solution space and focuses on the small part that contains the optimal and near-optimal solutions. The following sections discuss this in more detail.

1.3.1 Classification of Design According to the Level of Difficulty

Based on the degree of difficulty, design can be classified as *adaptive design, development design*, and *new design*.

Adaptive design: In the great majority of instances, the designers' work will be concerned with the adaptation of existing designs. There are branches of manufacturing in which development has practically ceased; there is hardly anything left for the designer to do except make minor modifications, usually in the dimensions of the product. Design activity of this kind demands no special knowledge or skill, and a designer with ordinary technical training can easily solve the problems presented. One such example is the elevator, which has remained the same technically and conceptually for some time. Another example is a washing machine. This has been based on the same conceptual design for the past several years and varies in only a few parameters, such as its dimensions, materials, and detailed power specifications.

Developmental design: Considerably more scientific training and design ability are needed for developmental design. The designer starts from an existing design, but the final outcome may differ markedly from the initial product. Examples of developmental design include moving from a manual gearbox in a car to an automatic one and moving from the traditional tube-based television screen to the modern plasma and LCD versions.

New design: Only a small number of designs are new designs. This is possibly the most difficult level because generating a new concept involves mastering all the skills needed to work on the previous two categories in addition to creativity and imagination, insight, and foresight. Examples of this are the design of the first automobile, airplane, or even the wheel (a long time ago). Take a moment to think of entirely new designs that have been introduced during the past decade.

1.3.2 Modular Design

Modular design is a technique whereby units or modules that perform distinct functions and are easy to assemble are designed and developed so that different combinations of them could be assembled to develop distinctly different products. A good example of modular design is a personal computer. The modules involved are the memory chips, hard discs of various sizes, CD drives, and graphics cards along with many other modules. The basic product can have various combinations of modules resulting in different configurations with different functionalities. Classifying the design task as modular or otherwise at the beginning can narrow down the research area considerably. Further it enables the use of any *design methods* (special techniques) in modular design.

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1.3.3 Platform Design

In simple terms, a product platform consists of the basic design and components that are used in several products or in a family of products. It is the structural or technological form from which various products can emerge without the expense of developing a new process or technology. Examples of platform design include power tools, cars, and printers. To elaborate, a family of cars in platform design share the same platform but differ in some features; for example, although the motor and the structure are the same for two different car products, some features such as seating may distinguish two car products.

A famous example of how the platform approach to development design could be a key success is the development of the 35-mm single-use camera. In 1987 Fuji introduced the QuickSnap 35-mm camera in the U.S. market and was able to dominate the market for a short time. Kodak was able to take the market back in 1994 by developing three different cameras that share common platform. Platform design is a key approach that allows tailoring products to meet individual customers' needs and also allows differentiated products to be delivered to the market without consuming excessive resources. Robertson and Ulrich [5] define a platform as "the collection of assets that are shared by a set of products." These assets may include components, knowledge, and production processes. Effective platform planning balances the market value of product differentiation against the economies achieved through commonality and thus reduces the research area in the design solution space.

1.4 CONVENTIONAL DESIGN PROCESS

The conventional design process can be best introduced by describing a meeting with an older traditional designer in the 1980s. Two students (one of the authors was one) and their professor visited the managing director and founder/owner of a company that designed and supplied products to the Ministry of Defense for the United Kingdom's government. The professor was a good friend of the designer. The designer enthusiastically received and offered tea to the visitors. While having tea, the designer got a call to attend to an urgent problem at the factory. The three visitors were invited to wander around the office to pass the time while the designer rushed to the factory. The office was fairly large and had four drawing boards with drawing papers with half-developed drawings clipped on them. No one was working on them. There were a calculator, a white board, and marker pens. The designer returned, and the professor told his friend that the students were curious to know why there were four drawing boards that had no one working on them. Oh that is my "brainstorming room" replied the designer. He then took the three visitors and started explaining. On the first board, he had developed the idea for a product for the defense ministry, and halfway into it, he realized that it would not work within the given constraints. He then moved to the second board and started working fresh. He soon progressed to a level beyond the previous one. Again he realized that it would not work. He then moved to the third board and made substantial progress there. However, now he realized that he could incorporate some parts of his first idea into the third idea. The board and the marker pens would help to write down an occasional calculation or a spark of an idea. The office was in effect a mini-library with books and handbooks. The design process this designer employed can be summarized as follows:

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- The designer understands the problem well and can start work on a solution in earnest.
- No other help is made available other than what is provided by textbooks and handbooks.

- The solution to the problem lies within the designer.
- Immersion and long hours of thinking are the working methods.
- Different solution concepts are considered one after the other.
- Better insights can be achieved from unsuccessful concepts.
- The process continues until a working solution to the problem has been reached.

Similar accounts of activities can be seen in the annals of engineering designers. An account about James Brindley (the famous British canal builder) reads "When any extraordinary difficulty occurred, having little or no assistance from books or the labors of other men, his resources lay within himself. In order therefore to be quiet and uninterrupted while he was in search for necessary expedients, he generally retired to his bed; and he has been there for one, two or three days, till he had attained the object in view. He would then get up and execute his design, without any drawing or model. Indeed, it was never his custom to make either unless he was obliged to do so by his employers." [6]

Historically, design started with the craftsmen who made artifacts, which they improved by trial and error. Over time the products reached perfection. Technological advancement came slowly, and the product still remained current with the existing technology. Designs were the embodiment of the saying "A good carpenter will cut the wood twice; once in his head and once physically." There was no drawing. As the products became increasingly complex and required the application of science and mathematics, product development went into the hands of a new individual called the *design draftsman*. That changed a few decades ago when research in design and the introduction of computers into the design office moved product development into the hands of design engineers who practice the *systematic design process*.

1.5 INTRODUCTION TO SYSTEMATIC DESIGN

Engineering students during their training are presented with a vast amount of theoretical material and information. They face a challenge only when they are faced with the task of logically applying what they have learned to a specific outcome. As long as their work is based on familiar models or previous designs, the knowledge they possess is perfectly adequate for finding a solution along conventional lines. As soon as they are required to develop something already in existence to a more advanced stage or to create something entirely new without a previous design, they will fail miserably unless they have reached a higher level of understanding. Without a set of guidelines, they are at a loss for a starting point and a clear finishing goal line. The design process was formalized to enable both students and professional designers to follow a systematic approach to design and to help them guide their creativity and technical problem-solving skills to reach a satisfactory outcome.

The systematic approach to the design process divides the process into constituent components and utilizes the components to achieve the desired result. The process can be based on either (1) the intermediate stages (milestones) the design process goes through or (2) the activities that are carried out during the design process. When a systematic approach is adopted, no specific parts are overlooked and, more importantly, definite starting point and finishing point are defined.

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1.5.1 Design Stage Model

The *design stage model* uses the stage at which the design is at different time points during the product development to describe the design process. Different researchers have identified different landmark stages, as few as four to as many as nine. They all involve following the same basic stages, which are the stages used in this book:

- Requirements
- Product concept
- Solution concept
- Embodiment design
- Detail design

1.5.2 Design Activity Model

In the design activity model, we describe the process as a sequence of activities that occur during the design process. These can be more detailed for each of the stages and also can incorporate several steps as the complexity of the product increases. The requirements stage can incorporate activities such as (1) recording customer verbatim (statements/expectations), (2) converting customer verbatim to customer requirements, (3) defining metrics and units that provide each of the requirements and establishing the target specifications for a reasonably complex product. As the complexity of the product increases, it becomes fundamentally important to define the activities in each stage. Designers carry out an evaluation at the end of each stage before proceeding to the next stage. Such design models are called the *stage gate models*.

1.5.3 Design Methods

Cross [7] defines design methods as tools and techniques that can be used at different stages of the design process. The development of several design methods has occurred during the past few decades. Typical examples include brainstorming, collaborative sketching, decision matrix for concept selection, Pugh's matrix for concept evolution, and house of quality for eliciting customer requirements, among others. It has been said that there are several hundreds of design methods to choose from.

1.5.4 Scaffolding the Design Process

Scaffolding provides a framework that facilitates access to previously inaccessible parts of a building under construction and acts as a skeletal structure for constructing the building. In a similar fashion, the design model acts as a skeletal structure to the design process and enables the development of the intended design of the product. Pugh [8] states that the criteria for a design activity model are

- All must be able to relate to it.
- All must be able to understand it.
- All must be able to practice more effectively and efficiently as a result of using it.
- It must be comprehensive.
- It should preferably have universal application, owing allegiance to neither traditional discipline, industry, nor product.

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The activities of the design process largely depend on the magnitude and complexity of the product. As Pugh [8] rightly argues, the design model (or the scaffolding) should be built for each project.

The scaffolding or the design process model is built using the design stage model (described in the following section) as its basis, incorporating various appropriate design methods to complete each stage.

1.6 DESIGN PROCESS AND THE DESIGN MODEL

To design is to create a new product that generates a profit and/or benefits society in some way. As discussed previously, the design process is a sequence of events and a set of guidelines that helps the designer define a clear starting point—from visualizing a product in the designer's imagination to realizing it in real life. It should be done in a systematic manner without hindering the creative process. The *design model* describes the sequence of stages or activities that takes place during the process of converting an abstract set of requirements into the definition of a physically realizable system. The *design stage model* is more stable with a fixed number of stages; the number of activities carried out in each stage varies and depends heavily on the complexity and magnitude of the product.

Considering the two challenges facing the design team (1) in defining the problem and (2) in identifying the solution, the starting point can be only the identified societal need. The design brief outlines the goal or "what the product is," the objectives of the company, and who its customers are. In this process, the first challenge must be met. Once the problem has been well defined, the search for the solution, the second challenge, begins. With these aims in mind, the design stage model is created. At each stage, certain design activities are carried out, and there are several design methods to assist these activities. With these a design model can be devised for any given design project. Figure 1.2 illustrates the design model adopted in this book. It has the following five stages:

1. ***Requirements.*** The *requirements* stage starts with the design brief that comes from the senior management or a client of a design company. It describes what the product is (goal). There are several approaches to establish requirements. One method is described as follows. The design team understands the product as outlined in the design brief and carries out a survey among the customers and records what the customers say. The design team translates the customer's verbatim into customer requirements. The team then identifies measurable parameters or metrics that reflect how the customer requirements are provided in the design. With the metrics and their units, the design team works out the *target specifications*. Target specifications are the ideal specifications, which would satisfy the customers in full since they are drawn by considering the customer requirements only. Engineering and manufacturing considerations are added after an initial round of conceptual design, which often trims the target specifications.
2. ***Product concept:*** The product concept describes the functions the product should perform and the specifications that define the product. It is worth remembering at this stage that a *metric* and a *value* form a single specification. Product specifications are a collection of several individual specifications. Though the specifications are described in a solution-neutral form, they define the product to a great extent, and consequently it is called the *product concept*.
3. ***Solution concept:*** A *solution concept* is a sufficiently developed idea to be converted into structures that can behave as expected and provide the functions that are expected from the product or subsystem. The main task here is the identification of the optimal or near-optimal solution from the design-solution space. It is achieved in several stages, including concept generation, concept evolution, concept prototyping and

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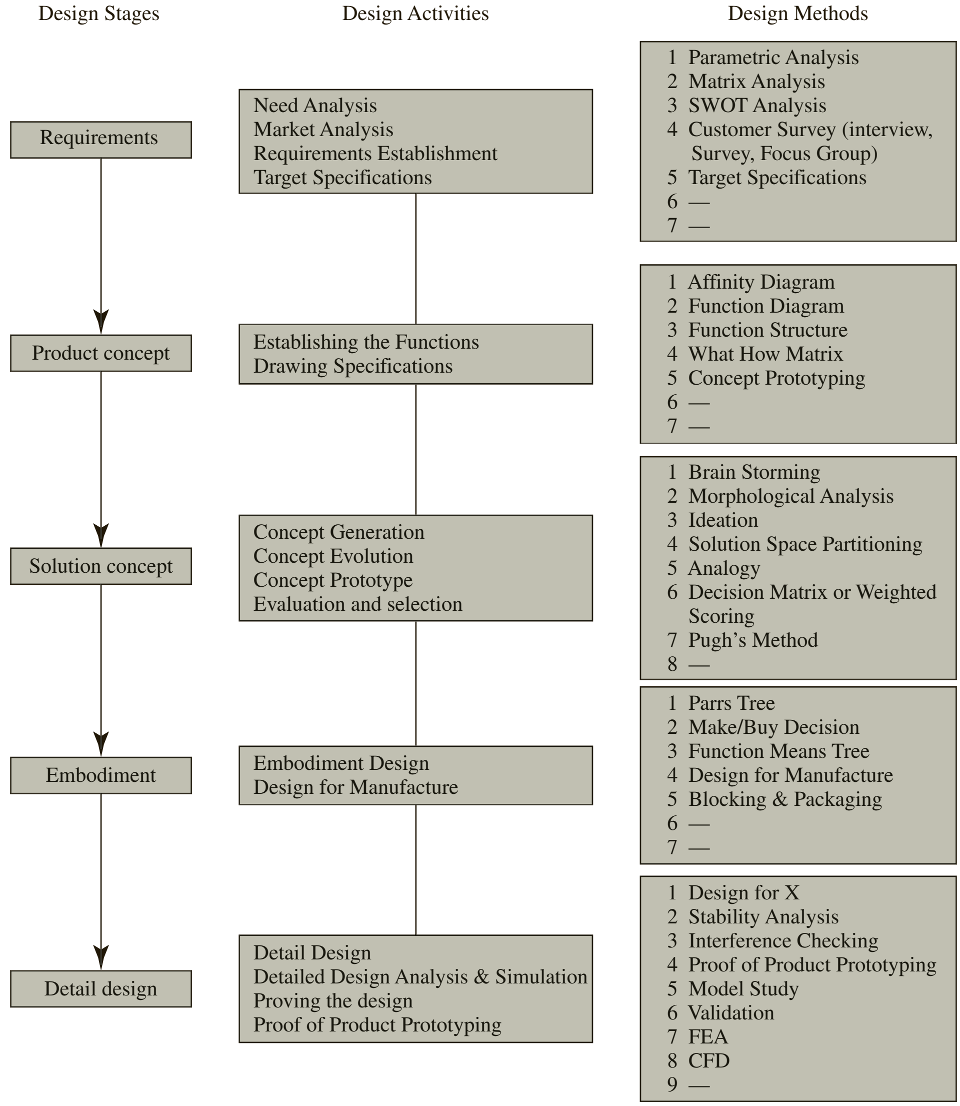

Figure 1.2: Adopted Design Model

proving, and evaluation and selection. Conceptual design is a difficult and important part of the design process, and there are several design methods available to assist.

4. ***Embodiment design:*** Embodiment design defines the hardware or physical form of the product. At this stage the main considerations are manufacturability and design for X. A large number of calculations and cross-checkings are made at this stage. Often the constraints are considered here, and they may condemn a solution as unacceptable even though it is acceptable in all other ways except for a constraint.
5. ***Detail design:*** The detail design comprises two main parts: (1) definition of the geometry, materials, dimensions, and permissible tolerances required for manufacturing and (2) detailed design or the engineering calculations required to ensure correct functionality and safety in operation. The following subsections describe some of the activities and items related to activities in the model proposed.

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1.6.1 Identifying Customer Needs (Requirements Stage)

No matter how much a product is functionally sophisticated and elegant in appearance, if it does not meet a societal need, it will not succeed in the market. The elements of the need expressed by the customer are called *customer requirements*, or simply, *requirements*. All of these requirements are not equally important. Some can be fundamentally important or mandatory, while some may come from the list of items “good to have.” A weight factor to express the degree of importance is attached to each of these requirements. Thus, the need is expressed as a list of prioritized requirements. The importance ratings are then translated to the specifications derived from them, and the important specifications are used in concept selection. A good set of prioritized requirements will help the design team to distinguish between the principal and secondary function carriers during embodiment design.

The most important step of the design process is identifying the requirements of the customer—the *requirements*. However, before this is done, it is important to establish who the customers are. A vital concept to grasp here is that customers are not the only end users. Customers of a product are all those who will deal with the product at some stage during its lifetime. For example, the person who will sell the product is also a customer. A designer must make the product attractive for the seller to agree to advertise and market it. Another example of a customer is the person who will service and maintain the product during its lifetime in operation. If a product is difficult to maintain and/or service, independent service providers will be keen to recommend other products or charge more to service the item and so on. As a group these people are called the stakeholders. Consider the possible stakeholders of an airplane. The list can include

- Passengers
- Crew
- Pilot
- Airport
- Engineers and service crew
- Fueling companies
- Airlines
- Manufacturing and production departments
- Baggage handlers
- Cleaning and catering companies
- Sales and marketing
- Accounts and finance
- Military/courier/cargo/etc.
- Authorities and official bodies
- Companies involved with the items that will be outsourced

Each of these customers can have entirely different (and sometimes conflicting) needs for the same product. By identifying these customers first, it is possible to identify their requirements as a whole and to arrive at a reasonable compromise according to priority and feasibility. The need for a new design can arise from several sources, including the following.

Client request: In a design company, clients may submit a request for developing an artifact. It is often unlikely that the need will be expressed clearly. The client may know only the type of product that he or she wants; for example, “I need a safe ladder.”

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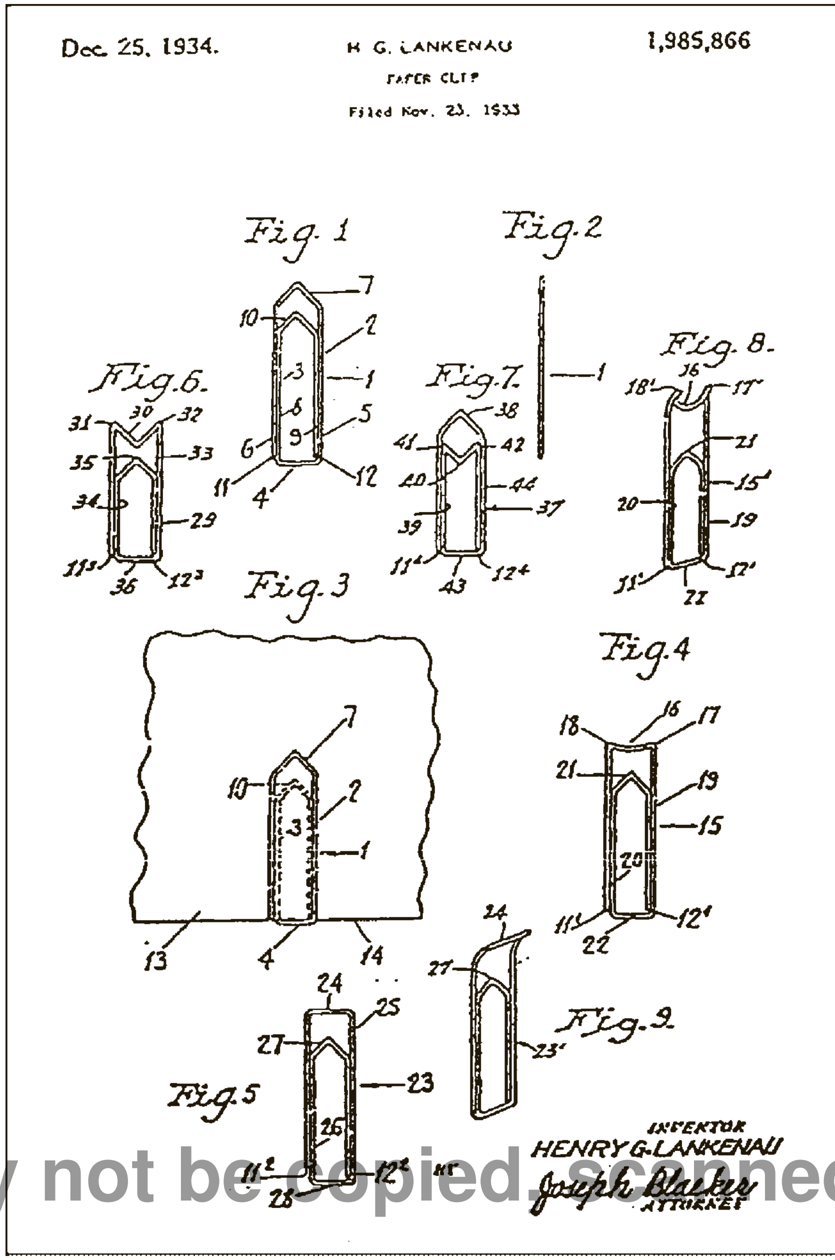
Modification of an existing design: Often a client will ask for a modification of an existing artifact to make it simpler and easier to use. In addition, companies may want to provide customers with new, easy-to-use products. For example, a market search will identify many brand names for coffee makers and detail the differences among them, in terms of shape, material used, cost, or special features. Looking at the market will help you to identify gaps and introduce a new product of your own. As another example, Figure 1.3 through 1.5 demonstrate design developments for paper clips. Each of the designs has its own advantages over the other ones. For example, the endless-filament paper clip can be used from either side of the clip. One might argue that the different designs are based on the human evolution of designs and the birth of new ideas. However, one of the major driving forces for the renovation of designs is to keep companies in business. The first patent for a paper clip



Lankenau's Gothic clip design patent, issued in 1934.

Figure 1.3: Patent of Gothic-Style Paper Clip, Issued in 1934

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